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A quantitative assessment of energy strategy evolution in China and US

Huiming Zhang [a,*], Dequn Zhou [b], Jie Cao [a]

[a] College of Economics and Management, Nanjing University of Information Science & Technology, Nanjing 210044, China
[b] College of Economics and Management, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

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ABSTRACT

Energy strategy evolution of China and US is assessed quantitatively based on Bai and Perron' s structure breaks test. Results indicate no break for time series of energy intensity, while series of carbon emissions per GDP, proportion of renewable energy production and oil importing reliance are characterized as segmented trend stationary process around one or two structural breaks. Execution of China and US energy strategies does not change the growth path of carbon emissions per GDP, and the pollution caused by energy production and consumption is one of the problems to be solved urgently. The impact of China energy strategy on the proportion of renewable energy production is inconsistent with that of US, suggesting that China can learn from the diversified energy supply, renewable energy quota system policies, and R&D incentive policies of US. Energy strategies in China and US pose a significant impact on the oil importing reliance, indicating that the strategy to reduce the oil dependence from US is not working.

Contents

1. Introduction

China and US take a pivotal position on the world energy production and consumption, and have a major influence on the world's energy industry. In 2007, the energy production of US amounted to 1.665 billion tons oil equivalent, which was 13.95% of the world energy production, and US was the second largest energy producing country in the world. China was the largest one in the world with 15.19% of the world energy production, 1.814 billion tones oil equivalent. As for the energy consumption, the energy consumption of US amounted to 2.361 billion tons oil equivalent in 2007, which was 21.3% of the world energy consumption; while the energy consumption of China amounted to 1.863 billion tons oil equivalent, was 16.8% of the world energy consumption and 50% of global energy consumption growth.

Since the oil crisis in 1970s, all US governments put much effort on energy strategy issues, and successively formulated series of long-term and directional strategic measures to address the energy issues, such as Energy Supply and Environmental Coordination Act of 1974, Energy Policy Conservation Act of 1975, Economic Recovery Tax Act of 1981, Electric Consumers Protection Act of 1986, Clean Air Act Amendments of 1990, National Energy Strategy of 1991, Energy Policy Act of 1992, Energy Policy Act of 2005, Energy Independence and Security Act of 2007, Emergency Economic Stabilization Act of 2008 and Obama's Green New Deal of 2009. The enforcement of US government's energy strategy has enhanced the energy security, stability and low-cost supply effectively, and improved the energy efficiency to a certain extent,

* Corresponding author. Tel.: +86 13914741963; fax: +86 2584896261.
E-mail address: hm.zhang_16@163.com (H. Zhang).

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but the issues such as excessive dependence on foreign oil, high carbon emissions, and so forth, still exist.

Compared with US, China energy strategy started from the reform and open up. In the context of energy strategy guidance and energy policy implementation, Chinese energy supply capacity was strengthen in 30 years; the energy consumption structure was continuously optimized; the energy industry management system reform was smoothly promoted and energy-saving effect was significant, which effectively gave rise to the sustained and rapid economic growth. However, China still has four energy predicaments currently: (1) the contradiction between richness in gross energy resources and insufficiency in per capita amount; (2) the contradiction between high-quality energy demand and a serious shortage of domestic supply; (3) the contradiction between energy shortage and low energy efficiency; (4) the contradiction between serious environmental pollution and contaminated energy structure [1]. Recognizing those problems, this paper attempts to summarize experiences and lessons from previous energy strategies based on quantitative assessment of energy strategy evolution in China and US.

2. Literature review

Currently, the research work related to the evolution of the US energy strategy can be categorized as follows.

(1) Evaluate the prospects and implementation of act in the context of comprehensive energy strategy or policy. Paul assessed US energy policies of three stages as pre-1990, 1990–1992 and 1993–2000. According to the author, the federal government's energy policies during the 70s and 80s stressed energy conservation, energy efficiency, energy diversification and energetic environmental policy measures. For the energy policies of 1992–1995. Paul [2] mainly discussed Energy Policy Act of 1992 and pointed out that the act matched the energy policies of Clinton administration, which primarily addressed the issues regarding the energy efficiency, renewable energy and so on. Robert [3] expounded energy policies after oil embargo of 1973–1974, indicating that energy strategy from the 70s to 80s emphasized the energy conservation, efficient use of energy and exploitation of alternative energy sources, whereas, the drop of fossil energy prices led to the complicated effects of new enacted energy-saving and energy efficiency projects. Fan and Fan [4] evaluated the core contents of Energy Independence and Security Act of 2007 based on introduction of policies and acts evolution since 1975, suggesting that US energy strategic adjustment focused on demand management in order to improve energy efficiency, accelerate the development of new energy, slow demand growth rate, reduce foreign oil dependence. Appraising US policies of energy independence and recovery, energy consumption, and evolution of energy incentive policies, Wikipedia noted that energy alternatives and diversification of oil supply were crucial for the energy independence and resilience plan of 1973; President Carter's energy consumption policies such as Weatherization Assistance Program reduced costs, improved energy efficiency and made great achievements in investment [5]. Jin et al. tested the impact of US energy prices and energy conservation of post-war on the economic growth using an econometric model. The vector auto-regression model included variables of real GDP, real capital, labor, real energy prices and Divisa Energy Index. Results showed that energy-saving did not impact macroeconomy significantly in the short-term [6].

(2) Analyze energy security, renewable energy or climate change policies especially. Wu [7] interpreted Bush administration's energy security strategy which aimed to reduce foreign oil dependence. The author merely pointed out that a few crucial issues as stressing energy security and energy infrastructure construction in Bush administration, and did not evaluate the effects of the national energy strategy. Frank and Christoph [8] compared the renewable energy policies between the United States and Germany since energy crisis in the 1970s, which indicated that the distinctive institution determined policy differences between the two countries. Miguel analyzed the evolution of renewable energy policies from aspects of incentive polices and tax credit of the US. As reviewed by Miguel, supported policies of energy property diversification needed to be combined with stable financing plan in order to promote the development of renewable energy industry [9]. Paul [10] recounted evolution in US policies from environmental leader to environmental laggard, and summed up US climate change policies and diplomacy. Similarly, Yan [11] expressed the legislation process of US Congress during Clinton and Bush administration. According to Yan, the Congress had not yet made substantial results closely related to US pursuing national supremacy interests, US domestic situation and characteristics of political structure.

Only a few literatures reviewed energy strategy revolution in China, which were classified as: (1) Analyze evolution strategy according to energy types. Wu and Li [12] examined the national policies and regional strategies' evolution of oil, coal, natural gas and electricity, etc., and made comprehensive assessment on Chinese energy development. According the authors, there were two characteristics for Chinese energy policies: first, the policies during the past few decades changed with civil and abroad environment; second, China lacked an unified national energy strategy. Dividing Chinese renewable energy policies into three categories, Li et al. [13] regarded that the obstacles of renewable energy development were high initial costs, high transaction costs, lack of product acceptability, lack of policy environment and inappropriate non-market-oriented R&D. Chen et al. [14] constructed the evaluation index system, established Chinese National Petroleum's oil security strategy evaluation model to make empirical analysis with gray relational method and data from 1990 to 2006. (2) Research on implementation effects of energy strategy based on types of policies. Chinese Energy Development Strategy and Policy Research Report Force classified implementation of Chinese major energy policies into three different levels and assayed implementation effects of policies as "Comprehensive Energy Strategy and Policy Evaluation", "Resources", "Power", "Rural Energy and New Energy", "Energy Efficiency and Conservation", "Environmental, Safety and Health", "Reform", "Economic Policy" and "Opening up", summing up the major experiences and lessons of energy policies implementation [15]. Although the classification was detailed, it lacked data in support of evaluation. (3) Investigate energy strategy and its performance in accordance with energy supply and energy efficiency. Xu appraised strategy implementation effects of three stages during the process of Chinese energy development. The three stages are open-source, comprehensive energy efficiency, coordination between energy and economy, respectively [16]. Compared with Wu and Chinese Energy Development Strategy and Policy Research Report Force, Xu clearly identified each energy strategy, whereas the research was deficient in the data support and environment issues.

To summarize, energy strategies of China and US were mainly reviewed from four aspects as energy efficiency, energy alternatives, energy environmental impacts, energy dependence on foreign countries, among which the alternative energy refers to the renewable energy development, environmental impact is mainly manifested by CO_2 emissions. Based on the analysis, this paper attempts to establish indicators which represent energy efficiency, energy substitution, energy environmental impacts, and dependence on foreign energy to evaluate energy strategy evolution in China and US quantitatively with BP break test.

3. Methods

BP break test can be used to examine both the existence of sub-trend stationary process around structural breaks and the number of breakpoints. If a time series is sub-trend stationary process around structural breaks, the impact of structural breaks exerts lasting influence on economic aggregate, and changes its growth path.

Since the open policy, China's energy strategy has experienced several structural changes, and the indicators reflecting energy strategy performance could vary with the major energy strategy adjustments. Therefore BP break test is applicable to make empirical analysis on energy strategy evolution.

Consider the linear regression model with m breaks as follows:

$$y_t = x_t'\beta + z_t'\delta_1 + u_t, \quad t = 1, 2, \ldots, T_1; \tag{1}$$

$$y_t = x_t'\beta + z_t'\delta_1 + u_t, \quad t = T_1+1, T_2+2, \ldots, T_2; \tag{2}$$

$$y_t = x_t'\beta + z_t'\delta_{m+1} + u_t, \quad t = T_m+1, T_m+2, \ldots, T; \tag{3}$$

where y_t is the observed dependent variable at time t; x_t, and z_t are vectors of covariates; β and $\delta_j (j = 1, 2, \ldots, m+1)$ are the corresponding vectors of coefficients; u_t is the disturbance at time t; $T_1, T_2, \ldots, T_m$ are break points. Note that this is partial structure change model, when $x_t = 0$, we obtain a pure structure change model where all the coefficients are subject to change, the multiple linear regression system can be expressed in matrix form as:

$$Y = X\beta + \bar{Z}\delta + U, \tag{4}$$

where $Y = (y_1, \ldots, y_T)'$, $X = (x_1, \ldots, x_T)'$, $U = (u_1, \ldots, u_T)'$, $\delta = (\delta_1', \delta_2', \ldots, \delta_{m+1}')'$, and $\bar{Z}$ is the matrix which diagonally partitions Z at $(T_1, T_2, \ldots, T_m)$. Based on this, Bai and Perron [17] proposed four tests to determine the exact number of breakpoints and time of occurrence. First consider the sup wald type of no structure break $(m = 0)$ versus the alternative hypothesis that there are $m = k$ breaks. Define

$$F_T(\lambda_1, \lambda_2, \ldots, \lambda_k, q) = \frac{1}{T}\left|\frac{T-(k+1)q-p}{kp}\right|\hat{\delta}R'(R\hat{V}(\hat{\delta})R')^{-1}R\hat{\delta}, \tag{5}$$

where p and q are the number of dependent (or explanatory?) variables as x_t and z_t, respectively. $\lambda_i = T_i/T$, $(R\delta)' = (\delta_1' - \delta_2', \ldots, \delta_k' - \delta_{k+1}')$, and $\hat{V}(\hat{\delta})$ is an estimate of the variance covariance matrix of $\hat{\delta}$that is robust to serial correlation heteroskedasticity. In general, the researchers have not pre-assumed that the number of specific breakpoints of breaks, thus Bai and Perron provided two tests of the null hypothesis of no structural break against an unknown number of breaks given upper bound M. Construct statistics

$$UD\max F_T(M, q) = \max_{1\le m\le M} F_T(\hat{\lambda}_1, \ldots, \hat{\lambda}_2, \hat{\lambda}_m; q), \tag{6}$$

and

$$WD\max F_T(M, q) = \max_{1\le m\le M} \frac{c(q, \alpha, 1)}{c(q, \alpha, m)} F_T(\hat{\lambda}_1, \hat{\lambda}_2, \ldots, \hat{\lambda}_m; q), \tag{7}$$

where $\hat{\lambda}_i = \hat{T}_i/T (i = 1, 2, \ldots, m)$, $c(q, \alpha, m)$, is the asymptotic critical value of $\max_{1\le m\le M} F_T(\hat{\lambda}_1, \ldots, \hat{\lambda}_2, \hat{\lambda}_m; q)$ for a significance level α. The three tests are mainly used to determine the breaks existence of time series. On this basis, Bai and Perron [18] proposed a test for l versus $l+1$ breaks, that is

$$\sup F_T\left(\frac{l+1}{l}\right) = \frac{S_T(\hat{T}_1, \ldots, \hat{T}_l) - \min_{1\le i\le l+1} \inf_{\tau\in\Lambda_{i,\eta}} S_T(\hat{T}_1, \ldots, \hat{T}_{i-1}, \tau, \hat{T}_i, \ldots, \hat{T}_l)}{\hat{\sigma}^2} \tag{8}$$

$$\sup F_T\left(\frac{l+1}{l}\right) = \{S_T(\hat{T}_1, \cdots, \hat{T}_l) - \Lambda_{i,\eta}$$
$$= \{\tau, \hat{T}_{i-1} + (\hat{T}_i - \hat{T}_{i-1})\eta \le \tau \le \hat{T}_i - (\hat{T}_i - \hat{T}_{i-1})\eta\} \tag{9}$$

$\hat{\sigma}^2$ is the consistent estimator of residual item variance for the null hypothesis, η is the minimum limit to each sub-interval length for ensuring test effectiveness, and generally set $\eta = 0.05T$.

4. Empirical analysis

4.1. Variables and data

In accordance with actual situation of energy strategy development in China and other countries, we study the effects of China and US energy strategy evolution by choosing energy consumption per unit GDP, carbon emissions per unit GDP, proportion of renewable energy accounted for energy production and oil importing reliance as variables. The energy consumption per unit GDP reflects a country's energy utilization efficiency; Carbon emissions per unit GDP indicates the level of coordination of economic and environmental development; because China and US take the diversification of energy as an important component of strategy, the proportion of renewable energy accounted for energy production, reflects energy substitution and diversification; oil importing reliance is measured by oil imports/total oil consumption, which reflects a country's external energy dependence.

According to the study of Chinese Energy Development Strategy and Policy Research Report [15] and Xu [16], China's energy strategy started from the reform and opening up, and marked by the slogan: "Energy is the most important economic issues" proposed by Deng Xiaoping in 1980 and the central government's slogan: "lay equal stress on development and conservation, give priority to energy conservation for short term"; while on the basis of Paul [2], Robert [3], US energy strategy started in 1973 oil embargo. Therefore, to facilitate a comparative study between China and US, this paper unified the period from 1980 to 2006. The sample data are acquired from BP Statistical Review of World Energy (2008), EIA official website of the United States, Comprehensive Statistical Data and Materials on 50 years of New China. As for data processing, we unify the energy consumption per unit GDP and carbon emissions per unit GDP of the two countries as Btu/dollars, tons/thousands of U.S. dollars (according the US comparable prices in 2000), respectively, and take natural logarithm of the four variables, variables denoted by $\ln CG$, $\ln RE$ and $\ln IM$, respectively.

4.2. Empirical analysis results

Empirical analysis results indicate that all of the variables cannot rejects the existence of structural breaks. At 5% significance level, there are 2, 2 and 1 breaks for Chinese carbon emissions, the proportion renewable energy production accounted for total energy production and dependency on oil imports, respectively, accordingly 1, 1 and 1 breaks for US (Tables 1 and 2).

Segmented trend stationary functions of Chinese time series are expressed as:

$$\ln CG_t = 8.315 - 0.362t - 0.452DU_t + 0.104tDT_{t1} \tag{10}$$

$$\ln CG_t = 7.863 - 0.258t - 7.888DU_t + 0.368tDT_{t2} \tag{11}$$

$$\ln RE_t = 4.127 + 0.050t - 2.965DU_t + 0.249tDT_{t1} \tag{12}$$

$$\ln RE_t = 1.162 + 0.299t + 1.398DU_t - 0.099tDT_{t2} \tag{13}$$

$$\ln IM_t = -16.292 - 2.586t - 43.841DU_t + 6.727tDT_{t1} \tag{14}$$

Table 1
BP break test results (China).

BP test	$SupF_T$ (1)	$SupF_T$ (2)	UDmax	WDmax	$SupF_T$ (2/1)	$SupF_T$ (3/2)
ln *CG*	589.00***	553.70***	589.00***	694.91***	143.98	–
ln *RE*	42.13***	30.03***	42.13***	42.13***	541.47***	–
ln *IM*	189.68***	–	189.68***	189.68***	–	–

*** Represents 1% significant level (similarly hereinafter).

Table 2
The number of breaks at 5% significant level (China).

Break time	T_1/year	T_2/year
ln *CG*	1986	2001
Confidence interval (95%)	1985–1987	2000–2002
ln *RE*	1993	2003
Confidence interval (95%)	1992–1994	2002–2006
ln *IM*	1985	
Confidence interval (95%)	1984–1986	

where DU_t and DT_t denote mean and trend dummy variables of structural breaks. $DU_t = 1(T > t)$, $DT_t = (t-1)1(t > 1)$, and for (10), (11), (12) and (13) denote stationary functions of carbon emissions per unit GDP and the proportion renewable energy production accounted for total energy production at different time, respectively.

Two breakpoints of carbon emission per GDP unit appeared in 1986 and 2001, respectively. Coefficients of trend dummy variables are positive, indicating that China's energy environmental governance policies produced unnotable success. While in practice, that Chinese government attaching importance to environment of energy development started in 1982, that Interim Measures for the Collection of Sewage Charges was passed in February subsequently, which stipulated collecting sewage charges for heating boiler dust, and did not exempted the enterprises to pay sewage charges from liability of controlling pollution, compensation for damage, etc. Nonetheless, low standard charges barely stimulate polluters to construct pollution control facilities actively. In addition, Chinese government revised Air Pollution Prevention and Control Law of People's Republic of China and restricted the serious sources of pollution. The law was formally implemented on September 1st, 2000, while the implementation was ineffective.

The break points of renewable energy appeared in 1993 and 2003. Intercept dummy variable coefficient of the first break is negative, while the trend dummy variable coefficient is positive; the second break is contrast with the former, indicating that the State strategy in 1992 had long-term effects on renewable energy by supporting small hydropower development and increasing expenditure on rural energy construction, which increased the growth rate of renewable energy production proportion accounted for total energy production. In 2003, the State Council Development Research Center issued Basic Concept of China's Energy Strategy, the use of renewable energy in China would reach 525 million tons of standard coal in 2020. However, lacking of incentive subsidies and taxes for renewable energy suppliers and demanders made renewable energy strategy undesirable effects, even reduced the proportion of renewable energy production in a long-term.

The break point of oil importing reliance appeared in 1985, dummy variable coefficient of intercept is negative, while the coefficient of trend is positive. Oil importing reliance increased from 38.61% in 1985 to 48.25% in 2006, indicating that China laid stress on oil security and strengthened international cooperation in the oil supply. For example, the State Council approved PRC Exploitation of Offshore Petroleum Resources in Cooperation with Foreign Parties Regulations in 1982, opening up the oil industry. On the other hand, the increase in oil importing reliance demonstrated that the lower level of oil self-sufficiency, and oil security had become a major constraint to economic development (Tables 3 and 4).

Segmented trend stationary functions of US time series are expressed as:

$$\ln CG_t = 0.947 - 0.031t - 0.106DU_t + 0.020tDT_{t1} \quad (15)$$

$$\ln RE_t = 8.764 + 0.024t - 8.897DU_t + 0.377tDT_{t1} \quad (16)$$

$$\ln IM_t = 42.657 - 1.464t - 10.149DU_t + 2.962tDT_{t1} \quad (17)$$

According to the calculating results, the break point of carbon emissions per unit GDP appeared in 1987, and the dummy variable coefficient of trend is positive, reflecting the Reagan administration's disregard for environmental governance. In the 1980s, Reagan administration regarded environmental regulation as an economic burden and adopted "anti-environmental" measures under economic stagnation and conservatism background: first, environmental deregulation. Reagan administration established a special working group to examine the federal laws amend or repeal some of the standards related to air quality, hazardous waste, industrial waste and toxic substance management laws and regulations. Reagan administration opposed the efficiency standards of equipment decreed by Carter administration and constructed a multi-level supervision system of federal control laws and regulations, which set up an unprecedented environmental control barriers and resulted in a substantial decline in the number of environmental regulations during the early 1980s; second, the decrement of environmental protection expenditures and the staffing. Federal government retrenched the R&D expenditures substantially, and reduced budget and staffing of EPA, the Occupational Safety and Health Administration and the Consumer Product Safety Commission. The enforcement of anti-environmental policies impacted carbon emissions growth vigorously, slowing down the rate of decline in carbon emissions per unit GDP.

The break point of renewable energy appeared in 2001. The dummy variable coefficient of trend is positive, suggesting that

Table 3
BP break test results (US).

BP test	$SupF_T$ (1)	$SupF_T$ (2)	UDmax	WDmax
ln *CG*	126.32***	–	126.32***	126.32***
ln *RE*	73.68***	–	73.68***	73.68***
ln *IM*	56.43***	–	56.43***	56.43***

*** Represents 1% significant level.

Table 4
The number of breaks at 5% significant level (US).

Break time	T_1/year	T_2/year
ln *CG*	1987	–
Confidence interval (95%)	1986–1988	–
ln *RE*	2001	–
Confidence interval (95%)	2000–2002	–
ln *IM*	1986	–
Confidence interval (95%)	1985–1988	–

Clinton administration's policies on renewable energy achieved a certain effects. Clinton administration announced a "Million Solar Roofs Plan" in 1997. By the plan, solar electricity price was planned to lower from 22 cents/kW in 1997 to 10.6 cents/kW in 2005. In 1998, Clinton administration submitted a comprehensive electricity competition rules, planning to enact a national renewable energy quota system policy (RPS) which required 7.5% of the electricity generated by renewable energy resources by 2010. To enhance the flexibility and effectiveness of RPS policies, regulations set renewable energy letter of trading and depositing in a bank to prepare for future use. In 1999, the federal government issued 13,123 executive order, and treated renewable energy and diversification of alternative fuels supply as a manifestation of national security interests. According to the executive order, federal government planned to install 20,000 solar energy systems by 2010, and encouraged vehicle manufacturers to develop alternative energy vehicles. The policies increased the proportion of renewable energy production accounted for total energy production.

The break point of oil importing reliance appeared in 1986.The trend dummy variable coefficient is positive, showing that the Regan administration's energy policies impacted oil importing reliance greatly. In 1981, President Regan signed "Deregulation of Oil Price and Allocation Control Bill", which stipulated loosen control of oil product imports by phrases and the ending of price control. After the implementation of the Bill, many old, inefficient small refineries were no longer competitive and forced to close. Therefore, the oil importing reliance on oil increased significantly.

5. Conclusions

We compare the performance of energy strategy evolution in China and US, and draw the following conclusions:

(1) No break exists in the time series of energy consumption per unit GDP of China and US, indicating that the energy strategy does not change tendency of energy intensity. Due to the fact that energy consumption per unit of GDP is nearly four times that of United States (in 2006 the energy intensity ratio of the two terms), Chinese reducing energy intensity is still a long way.
(2) China and US energy strategy does not change growth path of carbon emissions per unit GDP. The environmental pollution caused by energy production and consumption is one of problems to be solved promptly in the future, accordingly, the government should strengthen the related policy enforcement.
(3) It is inconsist for the impact of energy strategy on the proportion of renewable energy production between China and US. Results reveals that diversified energy supply and renewable energy quota system policies as well as R&D incentive policies are worth learning by China.
(4) Energy strategies of both countries strike oil importing reliance, increasing its growth rate. As low oil reserves in China and the remaining recoverable amount only last for 14 years, the limited self-sufficiency as well as growth trend of oil import reliance is an important restriction to energy security. Therefore, China or US government should develop the corresponding feasible measures to reduce oil imports reliance.

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